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RELATIONSHIP BETWEEN PLANT OCCURRENCES AND SURFACE CONDITIONS ON A RECENTLY DEGLACIATED MORAINE AT NY-ÅLESUND, SVALBARD, ARCTIC NORWAY

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Abstract: The relationship between plant occurrence and moraine surface conditions was studied in three areas along a deglaciated moraine (upper, middle and lower stream area from the glacier edge) in front of Brøgger glacier in Ny-Ålesund, Spitsbergen, Svalbard The total number of species in an area and the mean number of species in a plot (3 × 3 m) increased from the upper to the lower stream. Plants occurred according to a chronosequence following glacier retreat. The occurrence pattern of species within an area shows two types, a few common species and many remaining sporadic ones, suggesting haphazard establishment of plants within an area. Plots with high fine-textured material cover tended to have more species than plots with low fine-textured material cover in all three areas, suggesting that fine-textured material promoted the plant occurrence. In the upper stream plants occurred only on plots with high fine-textured material cover, while in the lower stream plants sometimes occurred on plots with low fine-textured material cover. The mean rock size at a stand also affects the plant occurrence in the upper and middle stream, although it showed rather negative correlation to the number of species in the lower stream.

key words: fine-textured material, High Arctic, moraine, plant succession, Svalbard

Introduction

Frontal moraines of retreating glaciers are among the best examples of primary succession. Plants usually occur on a moraine according to a chronosequence after glacier retreat. There have been many examples of the chronosequence approach to vegetation succession on moraines in glacier forelands, in North America (COOPER, 1923; VIERECK, 1966; BIRKS, 1980; LUCKMANN, 1988; CHAPIN, III *et al.*, 1994; HELM and ALLEN, 1995), Scandinavia (ELVEN, 1978), New Zealand (WARDLE, 1980), and Patagonia (SWEDA, 1987). Most of them discuss fairly long term successions from moss invasion to tree establishment. Only a few studies focus on plant occurrence on deglaciated moraines in the Arctic.

On deglaciated moraines in the Arctic it is possible that plants appear according

to a chronosequence. In addition, surface moraine conditions such as soil moisture, soil nutrients, fine-textured material cover and rock size also possibly affect the occurrence of plants (CONNELL and SLATYER, 1977; PICKETT, 1980). However, it remains unclear how plants occur just after deglaciation within relatively short time spans in the Arctic.

The deglaciated moraines in Svalbard, Norway, are situated in the High Arctic (ALEKSANDROVA, 1980). A number of studies review the flora (RØNNING, 1996; ELVEBAKK and PRESTRUD, 1996) and vegetation of Svalbard (SUMMERHAYES and ELTON, 1923; ELVEBAKK, 1985, 1994; HADAC, 1989; KOBAYASHI, 1994; for bibliography, SUNDING, 1990), and a 1:10000 scale vegetation map of the Ny-Ålesund area has been made (BRATTBAKK, 1981). However, there is insufficient information on plant occurrence on moraines in the initial phase after glacier retreat (less than one hundred years), although some studies have been done in the same study area (MINAMI and KANDA, 1995; MINAMI *et al.*, 1996, 1997).

This paper deals with 1) the chronosequential occurrence of plants, and 2) effects of surface conditions of the moraine on the plant occurrence, on the deglaciated moraine of Austre Brøggerbreen glacier in Svalbard, Norway.

Study Site

Svalbard is an archipelago including the major island Spitsbergen with neighboring islands (*ca.* 74°N, the isolated island Bjørnoya Isl., and between *ca.* 77° and 81°N, the main archipelago). Large parts are covered by glaciers. Austre Brøggerbreen glacier is located west of Ny-Ålesund (79°57.8′N, 11°21.2′E), north-western Spitsbergen, facing Kongsfjørden. The study area is situated in the middle arctic tundra zone according to the classification of ELVEBVAKK (1990), where the climax vegetation of zonal habitats is *Cassiope tetragona*.

The study site is an outwash moraine (less than 100 m in altitude) in front of Austre Brøggerbreen glacier, with *ca.* 1 km long and 500 m wide. The topography of the study site is an undulating complex of lateral moraines and end moraines. This glacier is estimated to be retreating 10–30 m/year, and the age of the end point of the moraine is less than 100 years based on photograph interpretations (SAWAGUCHI, pers. commun.).

The vegetation on the moraine is basically moraine community sensu BRATTBAKK (1981) with a plant cover of less than 5%, characterized by only scattered occurrence of bryophytes such as *Bryum cryophilum*, *Pottia heimii*, *Funaria arctica* etc. (MINAMI and KANDA, 1995; MINAMI *et al.*, 1996).

Three study areas were established on the moraine: upper stream, middle stream and lower stream below the glacier front, according to the occurrence of major species and changes in species diversity (MINAMI *et al.*, 1996). The upper stream is *ca.* 100 m distance from the glacier edge, the middle stream 400 m, and the lower stream 700 m. The estimated ages of the three areas are less than 10 years, 13–40 years, and 23–70 years, respectively (SAWAGUCHI, pers. commun.).

Methods

In each study area a 150 m transect was established, running parallel to the glacier edge and perpendicular to the longitudinal direction of the moraine. Thirty plots (3 × 3 m) were located successively at 2 m intervals along the transect. In each plot species occurrences were recorded. All plant occurrences were below 5% cover and quantitative cover estimates were therefore not made. Species nomenclature follows ELVEBAKK and PRESTRUD (1996). Voucher specimens are located in the herbarium of the National Institute of Polar Research, Japan. Because there have been problems with determinations of some plants with very scarce occurrence such as *Ceratodon* sp., *Desmatodon* sp., *Jungermania* sp., *Dicranum* sp., the observed species occurrences did not include all plants which should occur in the study areas. Nevertheless, the results indicate general pattern of occurrence of plants in the study areas.

The surface conditions of the moraine were surveyed in each plot, by analysis of fine-textured material (a mixture of silt, sand and gravel, usually dominated by sand) cover and rock (stones larger than 10 cm in longitudinal length) size. Fine-textured material cover was the percent cover of the total ground surface. Rock size was measured for the largest 30 rocks by longitudinal length.

Results

Species occurrence

The total number of species of the area increased from the upper to the middle and lower stream, being 10, 24 and 27 respectively (Table 1). The mean number of species per plot within an area also increased from the upper to the middle and the lower stream, being 2.8, 4.3 and 7.0, respectively. The number of species in an area and at the plot increases chronosequentially in the first 100 years after the glacier retreats.

In the upper stream four of the 10 species occurred commonly on more than 10 plots (species and number of plots were: *Bryum* sp. 24, *Funaria arctica* 21, *Bryum cryophilum* 14, and *Pottia heimii* 14), while the remaining six species occurred sporadically only in one to five plots.

In the middle stream the occurrence pattern of species was similar to that in the upper stream, although the total number of species increased to 24 species. Only five of the 24 species occurred commonly on more than 10 plots (species and number of plots were: *Bryum* sp. 26, *Funaria arctica* 20, *Saxifraga oppositifolia* 19, *Bryum cryophilum* 14, and *Pottia heimii* 12), while the remaining 19 species occurred sporadically on only one to five plots.

In the lower stream the occurrence pattern of species differed from those in upper and mid stream, although the total number of species (27) remained similar to that in mid stream (24). Eight of 27 species commonly occurred in more than 10 plots (species and number of plots were: *Saxifraga oppositifolia* 30, *Bryum cryophilum* 25, *Cerastium arcticum* 22, *Draba corymbosa* 18, *Stereocaulon* sp. 17, *Bryum* sp. 15, *Cerastium regelii* 13, and *Encalypta rhaptocarpa* 10). The remaining 19 species occurred in one to seven different plots.

Table 1. Species occurrences within 30 stands in three areas on the moraine in front of Austre Brøggerbreen glacier, Ny-Ålesund, Spitsbergen.

Species	Area		
	Upper stream	Middle stream	Lower stream
Bryum sp.	24	26	15
Bryum cryophilum	14	14	25
Ditrichum flexicaule	2	1	4
Saxifraga cespitosa	1	2	6
Distichium capillaceum	1	1	7
Encalypta rhaptocarpa	1	5	10
Cerastium arcticum	1	3	22
Funaria arctica	21	20	–
Pottia heimii	14	12	–
Bryum pseudotriquetrum	5	1	–
Myrinia pulvinata	–	3	–
Pohlia cruda	–	1	–
Silene acaulis	–	1	–
Oxyria digyna	–	1	–
Grimma sp.	–	1	–
Saxifraga oppositifolia	–	19	30
Cerastium regelii	–	4	13
Draba corymbosa	–	3	18
Stereocaulon sp	–	2	17
Poa alpina	–	2	3
Orthothecium chryseum	–	1	4
Sanionia uncinata	–	1	2
Calliergon sp	–	1	1
Saxifraga rivularis	–	1	1
Salix polaris	–	–	7
Silene uralensis	–	–	4
Deschampsia alpina	–	–	4
Arenaria pseudofrigida	–	–	4
Lecidea sp.	–	–	3
Cochlearia officinalis	–	–	3
Tortula sp.	–	–	1
Polytrichum sp.	–	–	1
Juncus biglumis	–	–	1
Cardamine pratensis	–	–	1
Draba lactea	–	–	1
Total number of species	10	24	27
Mean number of species per plot	2 8	4 3	7.0

Relation between number of species in a stand and surface condition of the moraine

Cover of fine-textured material positively correlated with number of species in the upper stream (Spearman rank correlation, $rs = 0.396$, $P < 0.05$; Fig. 1). In this area plants tended to occur favorably in plots with high cover of fine-textured material.

Cover of fine-textured material never correlated strongly with the number of species in the middle and lower stream as Spearman rank correlation showed no significance between them (Fig. 1). Nevertheless, no negligible relationship could be noted between

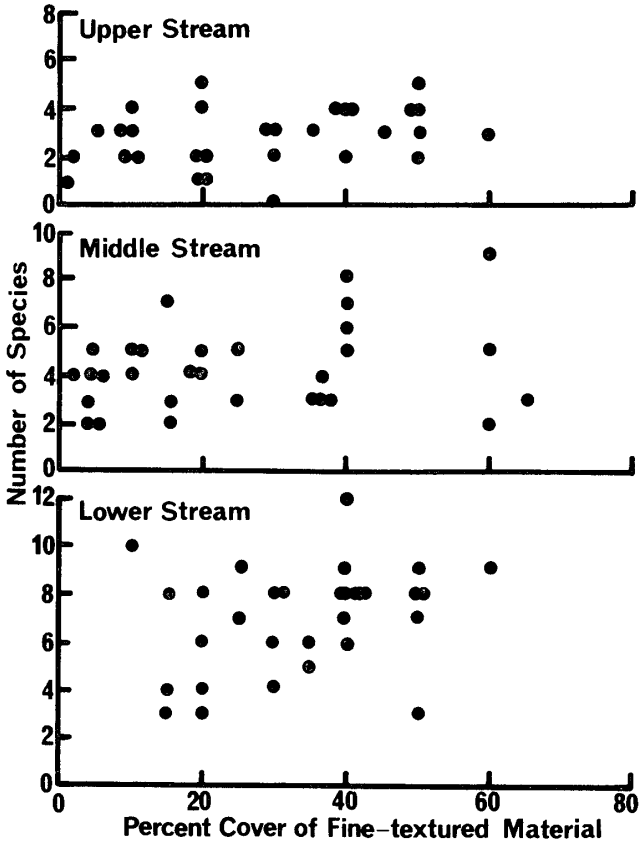

Fig. 1. Relationship between number of species in plots and fine-textured material cover (%) on three areas on the moraine in front of Austre Brøggerbreen glacier, Ny-Ålesund, Spitsbergen.

Table 2. Mean number of species on plots having different fine-textured material cover in three areas on the moraine in front of Austre Brøggerbreen glacier, Ny-Ålesund, Spitsbergen. Figures in parentheses under mean number of species show the number of plots.

Area	Fine material cover		Significance (U-test)
	<40%	40% ≦	
Upper stream	2.4 (19)	3.6 (11)	$P<0.05$
Middle stream	3.8 (22)	5.6 (8)	$P<0.05$
Lower stream	6.2 (16)	7.9 (14)	$P<0.05$

them in those two areas. The plots with fine-textured material cover above 40% had significantly higher number of species than those with fine-textured material cover below 40% (Table 2). Fine-textured material cover promoted the occurrence of plants also in those two areas.

The relationship between fine-textured material cover and number of species, however, differed among those two areas. In the middle stream, plots with low cover

Table 3 Mean number of species on plots having different mean rock size in three areas on the moraine in front of Austre Brøggerbreen glacier, Ny-Ålesund, Spitsbergen. Figures in parentheses under mean number of species show the number of plots

Area	Mean rock size		Significance (U-test)
	<25 cm	25 cm≦	
Upper stream	2 2 (11)	3 2 (19)	P<0.05
Middle stream	3 2 (10)	4 9 (20)	P<0 05
Lower stream	7.9 (18)	5 5 (12)	P<0 01

of fine-textured material commonly had a lower number of species, but plots with high cover of fine-textured material sometimes, but not always, maintained a higher number of species. In the lower stream, plots with high cover of fine-textured material commonly had a higher number of species, with one exception, and plots with low cover of fine-textured material sometimes, but not always, maintained a higher number of species.

Mean rock size of the plot had weak positive correlation with the number of species in the upper and middle stream, although Spearman rank correlation showed no significance between them. Plots with a mean rock size above 25 cm had a higher number of species than those with mean rock size less than 25 cm (Table 3). In those two areas, large rocks promoted the occurrence of plants. In the lower stream, however, mean rock size correlated significantly negatively with the number of species (Table 3).

Discussion

Plant occurrence

The increasing total number of species in the area and the mean number of species in the plots from the upper stream to the lower stream in this moraine confirms the chronosequential occurrence of plants on the moraine in the High Arctic, even within 100 years of deglaciation, a relatively short time span in a plant succession. MINAMI and KANDA (1995) also concluded that time after deglaciation was a major factor determining the species occurrence on this moraine. Thus, the time after deglaciation promotes plant occurrence in the High Arctic as well as in subarctic or boreal zones.

However, the existence of many sporadic species suggests a haphazard occurrence of plants especially within the areas of the upper and middle stream. In the upper stream area seven of 10 species are common in all three areas; occurrences increase, however, toward the lower stream except for *Bryum* sp. (Table 1). This fact suggests that only species having strong dispersal capacity can succeed in becoming fully established in the upper stream area. In the down stream area there are a number of species with intermediate occurrence, suggesting that some species will become fully established there.

Relation between plant occurrence and surface condition of the moraine

Plots with high cover of fine-textured material commonly maintain a higher number of species in all three areas. The fine-textured material on the moraine surface is a major factor determining the plant occurrence. Fine textured-materials are better than rocks and large stones for germination beds, especially in the frigid environment of the High Arctic. Plants tend to germinate and establish on fine-textured materials rather than on surfaces of rocks or large stones. The existence of rich fine-textured materials appears to be a critical condition for plant occurrence.

The larger mean rock size of the plot also supports higher numbers of species in the upper and middle stream areas. Large rocks function as a surface stabilizer on unstable, movable fine-textured materials on moraine surfaces near the glacier edge where melting water from the glacier makes many small temporary streams (ANIYA, 1987; REMPFLER, 1989). Large rocks in combination with fine-textured materials provide stable sites suitable for the establishment of plants. Actually almost all the plots in three study areas contain fine-textured materials to a certain extent.

In conclusion, fine-textured materials and large rocks are important for the occurrence of plants on this moraine, especially in the upper and middle stream areas. The former provides a favorable growing site for plants, while the latter makes the moraine surface stable, although the occurrences of plants are still haphazard in the upper and middle stream areas. Large rocks have, however, no major role in the lower stream. This suggests that the surface condition in the lower stream has become more stable than that in the upper and middle stream.

The different relationships between cover of fine-textured material and number of species between the three areas correspond to increasing stability of the moraine surface from the upper stream to the lower stream area. In the upper stream, the youngest area, the relationship is apparent. Fine material cover closely influences plant occurrence, probably because of surface conditions involving frequent and strong movements. In the middle stream, intermediate area, where the surface seems to be less easily movable than in the upper stream, the number of species increases only on plots with high cover of fine-textured material. In the lower stream, the oldest area, plots with low cover of fine-textured material sometimes keep higher number of species. A relatively stable surface here enables plants to occur rather easily, so that plants can grow even on fine material poor stand in some instances. Frequent occurrences of vascular plants of *Saxifraga oppositifolia*, *Cerastium arcticum*, *Draba corymbosa* and *Cerastium regelii* downstream demonstrate the stability of stands there.

MINAMI *et al.* (1996) found no systematic increase in soil nutrients and soil moisture downstream on this moraine. They pointed out that the plant occurrence in this moraine never correlated with such soil conditions as soil nutrients and soil moisture. On the contrary, fine-textured materials and large rocks are the major facilitating habitat factors for the occurrence of plants on this moraine. This finding in this paper is not in accordance with the prevailing view that in deglaciated areas the successional increase in soil organic matter, soil moisture and total N are significant facilitating habitat factors in plant succession following deglaciation (CROCKER and MAJOR, 1955; MESSER, 1988).

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